Archimedes / Aircraft

27% more lift for a wing that flies close to the ground or water.

Ground-effect craft skim just above the surface on a cushion of air, and run short of lift during take-off. Archimedes designed a wing section with 27% more lift under the same drag limit, in 2D simulation.

ARCHIMEDES TECHNICAL CASE STUDY

How to interpret this report

Results apply only to the stated geometry, operating conditions, numerical models, and verification record.
They are not product certification, safety approval, or a general claim outside the documented scope.
Limitations and adverse findings are retained because they are part of the engineering result.

REPORT ID
ground-effect-wing

CANONICAL SOURCE
standardphysics.com/archimedes/ground-effect-wing

27%
more lift than the best standard wing section, same drag limit

$174
total cost of compute and model use for the run

938
designs tried on 32 cloud machines in 3 hours

The ask

Get the most lift from a wing section flying low, without passing a drag limit.

Any number of wing elements allowed, inside a fixed box.

What it found

Tilting a single wing harder stalls it.

Past about 11 to 13 degrees the airflow separates and drag shoots past the limit.

What it did

Split the wing into a main element and a slotted flap.

Air through the slot keeps the flap working, while the angled flap builds more pressure under the wing.

Fine print

More lift, not more efficiency.

The standard section still has the better lift-to-drag ratio, and stability in pitch hasn't been checked.

For engineers

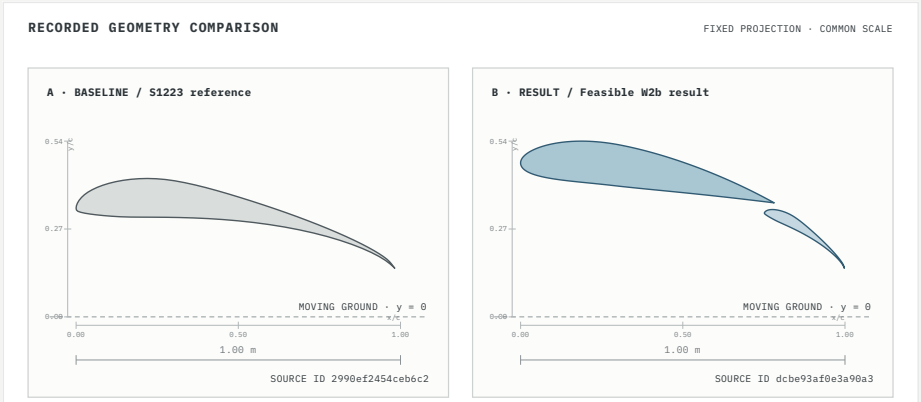
The full record, unedited.

Interactive comparison `explore the measured results` —

MEASURED COMPARISON

Lift under one fixed drag ceiling

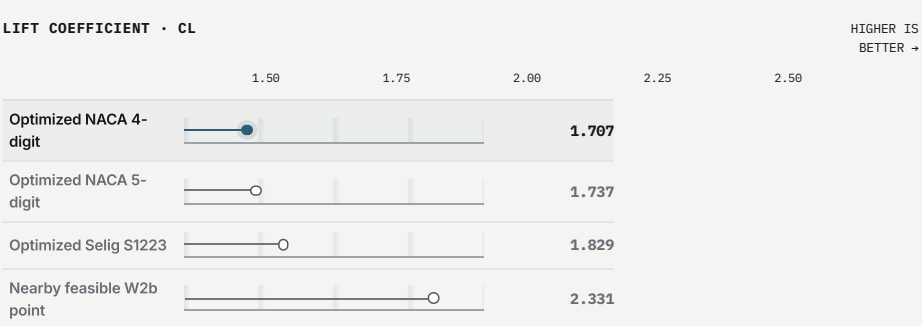
All candidates use the same moving-ground RANS evaluator at h/c 0.15. The plot compares lift while the plate holds the exact S1223 reference and feasible W2b geometry at one fixed projection. Lift and drag must be read together because the exact winner is mesh-sensitive.



Recorded 2D sections at h/c = 0.15. 1.0 m reference chord. Geometry is reconstructed from the recorded campaign artifacts.

Geometry only. No inferred streamlines, pressure field, or unrecorded physical detail is shown.

A source: results/evolve/robustness/wig_baseline/runs.jsonl · 2990ef2454ceb6c2 · Recorded CAD boundary tessellation of the exact 2D section with arbitrary display-span extrusion.
B source: results/evolve/robustness/wig_repeat/runs.jsonl · dcbe93af0e3a90a3 · Recorded CAD boundary tessellation of the exact 2D sections with arbitrary display-span extrusion.



SINGLE-ELEMENT BASELINE

Optimized NACA 4-digit

A conventional cambered section reaches its separation limit before using the full lift opportunity near the ground.

Cl 1.707

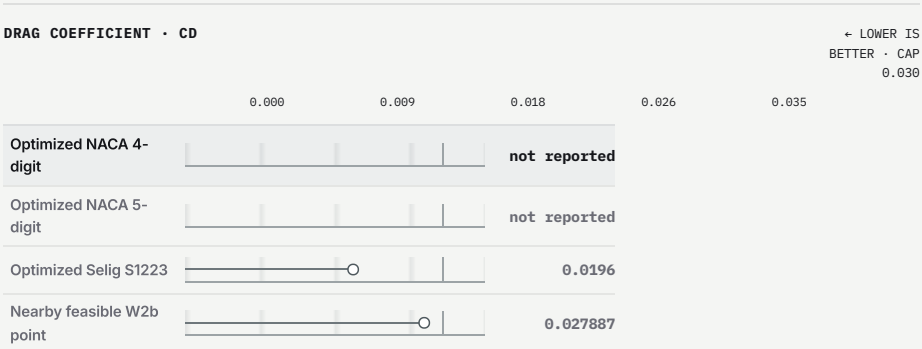
- 44 Bayesian evaluations
- Single element
- Same Cd 0.030 cap

SINGLE-ELEMENT BASELINE

Optimized NACA 5-digit

Extra camber adds lift, but the aft boundary layer still limits the usable incidence.

Cl 1.737



Drag is plotted only where the case record reports a paired value. The nearby W2b point remains below the Cd 0.030 acceptance line.

Numerical basis: 2D steady RANS (OpenFOAM simpleFoam, k-omega SST, moving ground wall, 1.5x refined mesh)

- 34 Bayesian evaluations
- Single element
- Same moving ground

BEST CONVENTIONAL SECTION

Optimized Selig S1223

The high-lift S1223 is the strongest single-element reference under the frozen evaluator.

Cl 1.829 at Cd 0.0196

- 13 Bayesian evaluations
- L/D 93
- Drag margin remains but separation limits lift

DRAG-CAP-COMPLIANT SEARCH-MESH POINT

Nearby feasible W2b point

A 26.6° flap seals the pressure cushion while a 21 mm slot feeds high-momentum flow onto its upper surface.

Cl 2.331 at Cd 0.027887

- 27.4% more lift than S1223
- Exact search-mesh repeat Cd 0.04365
- Refined candidate Cl 2.37522, Cd 0.028852

Lift at the drag cap

Moving-ground RANS at h/c = 0.15 and Re 3 million. Drag is shown only where the record gives a paired value.

Section	Cl	Cd	Status
NACA 4-digit optimum	1.707	At cap	Single-element separation limit
NACA 5-digit optimum	1.737	At cap	Single-element separation limit
Selig S1223 optimum	1.829	0.0196	Best conventional L/D, 93
Nearby feasible W2b	2.331	0.027887	Drag-cap-compliant search point
Refined W2b candidate	2.37522	0.028852	One refinement, not a GCI study

Why the exact repeat is not the headline

The exact search-mesh repeat crosses the acceptance line, so the reported lift gain uses the nearby feasible point.

Solve	Cd	Against cap 0.030
Nearby feasible point	0.027887	Accepted
Exact search-mesh repeat	0.04365	Rejected by the drag cap
Refined candidate	0.028852	Mesh-sensitive, one refinement only

Applicability

The +27% lift claim belongs to the nearby feasible 2D point, not to a grid-converged exact winner. Pitching stability, span effects, and a free surface are unresolved. S1223 retains the higher lift-to-drag ratio.

References and source records

Selig S1223 high-lift section, used as the optimized single-element reference.
Campaign lock: Re 3 million, 10 m/s, moving ground, k-omega SST, h/c 0.15, Cd at or below 0.030.

The exact brief as given to the agents

Maximize section lift coefficient Cl inside a 1.0 m x 0.5 m design box at ride height h/c = 0.15 above a moving ground wall (Re = 3 x 10^6, k-omega SST) subject to drag cap Cd <= 0.030. Open topology: any number of airfoil elements with >= 8 mm clearance.

ARCHIMEDES
3.0 h autonomous swarm search (938 CFD solves)

COMPUTE RECORD
32 cloud workspaces · $174 total compute + tokens

Decision log how the agents reasoned, step by step

REASONING TRACE

What changed, and why

The search first optimized the single-element references, then coordinated slot width, overlap, and flap angle in the literature-informed multi-element families so pressure capture and boundary-layer attachment improved together.

LITERATURE-INFORMED TOPOLOGY SEARCH

Co-optimizing a slotted section under a hard lift and drag objective

OBSERVED	INFERRED	CHANGED AND MEASURED
Single-element sections pushed above Cl ~ 1.83 separate on the rear upper surface or choke the ground channel, violating Cd <= 0.030.	Splitting the section into a main element and a steeply deflected trailing flap closes the exit nozzle toward the moving ground (raising cushion Cp), while a converging 21 mm slot bleeds high-pressure under-wing air onto the flap's upper	The refined candidate reached Cl = 2.37522 at Cd = 0.028852. The exact geometry exceeded the drag cap when repeated on the search mesh (Cd = 0.04365), while a nearby search point remained feasible at Cl = 2.331 and Cd = 0.027887.

boundary layer.

Engineering finding
headline numbers and the mechanism

More useful lift from the same geometric box

For a ground-effect craft, the computed lift margin could become payload or lower takeoff speed. The present result is a promising 2D section candidate, not yet a stable vehicle design.

+27.4%

lift coefficient over the best conventional single-element section under the same Cd <= 0.030 drag cap (Cl 2.331 vs 1.829 Selig S1223)

2D RANS CFD · feasible search-mesh point · h/c 0.15

0.0279

drag coefficient of the nearby feasible slotted two-element point (inside the 0.0300 budget)

Search mesh · Re 3e6

2.375 / 0.0289

lift and drag of the refined candidate; its exact geometry repeated at Cd 0.04365 on the search mesh

1.5x refined mesh · mesh sensitivity disclosed

Why the mechanism works

Among the literature-informed topology seeds, the strongest candidate combined a 5.1%-cambered main element at 9.6 deg incidence with a 26.6 deg aft flap and a 21 mm converging slot. The computed slot flow re-energizes the flap boundary layer while the deflected element raises ground-cushion pressure.

What the baseline got wrong

A two-seat ground-effect craft (ekranoplan) is lift-limited during low-speed take-off over water. Pitching a single-element airfoil above 11-13 deg to trap higher ram pressure under the wing causes massive trailing-edge flow separation that explodes drag past the Cd <= 0.030 limit.

Full technical record
appendices, families and limits

CAMPAIGN RECORD AND LIMITATIONS

Appendix

The detailed brief, decision record, search families, solver basis, and verification checks are exposed below without tabs or collapsed panels.

Appendix A: Frozen brief and campaign scale

Maximize section lift coefficient Cl inside a 1.0 m x 0.5 m design box at ride height h/c = 0.15 above a moving ground wall (Re = 3 x 10^6, k-omega SST) subject to drag cap Cd <= 0.030. Open topology: any number of airfoil elements with >= 8 mm clearance.

Search duration 3.0 h	**Evaluations** 938
Compute fleet 32 cloud workspaces	**Solver basis** 2D steady RANS (OpenFOAM simpleFoam, k-omega SST, moving ground wall, 1.5x refined mesh)

Appendix B: Full decision log

01 Hour 00:00 - 03:00 · Literature-Informed Topology Search

Co-optimizing a slotted section under a hard lift and drag objective

OBSERVATION

Single-element sections pushed above Cl ~ 1.83 separate on the rear upper surface or choke the ground channel, violating Cd <= 0.030.

REASONING

Splitting the section into a main element and a steeply deflected trailing flap closes the exit nozzle toward the moving ground (raising cushion Cp), while a converging 21 mm slot bleeds high-pressure under-wing air onto the flap's upper boundary layer.

ACTION AND RESULT

The refined candidate reached Cl = 2.37522 at Cd = 0.028852. The exact geometry exceeded the drag cap when repeated on the search mesh (Cd = 0.04365), while a nearby search point remained feasible at Cl = 2.331 and Cd = 0.027887.

Appendix C: Search families

37 section parameterizations. These are distinct programs or engineering configurations, not cosmetic renders.

- Cambered main element + 26.6 deg slotted flap (feasible W2b point, Cl 2.331 at Cd 0.0279)
- Slotted flap + Gurney tab family (Run W1, Cl 2.21)
- Bayesian-optimised Selig S1223 high-lift baseline (Cl 1.829 at Cd 0.0196)
- Bayesian-optimised NACA 4-digit (Cl 1.707) & 5-digit (Cl 1.737) families

Appendix D: Numerical basis and verification

2D steady RANS (OpenFOAM simpleFoam, k-omega SST, moving ground wall, 1.5x refined mesh)

Fair baseline: the swarm's own Gaussian-process Bayesian optimizer searched NACA 4-digit (44 evals), NACA 5-digit (34 evals), and Selig S1223 (13 evals) up to 16 deg incidence under the identical evaluator and drag cap.

Winner and S1223 baseline were re-solved back-to-back on one 1.5x finer body-fitted mesh. This is a refinement check, not a grid-convergence study.

The optimized S1223 has the better L/D (93 versus 82). The winner's more negative pitching moment, 3D tip effects, free-surface coupling, and dynamic stability remain unresolved.

Appendix E: Reported outcomes and limits

+27.4% lift coefficient over the best conventional single-element section under the same Cd <= 0.030 drag cap (Cl 2.331 vs 1.829 Selig S1223) Basis: 2D RANS CFD · feasible search-mesh point · h/c 0.15.	**0.0279** drag coefficient of the nearby feasible slotted two-element point (inside the 0.0300 budget) Basis: Search mesh · Re 3e6.
2.375 / 0.0289 lift and drag of the refined candidate; its exact geometry repeated at Cd 0.04365 on the search mesh Basis: 1.5x refined mesh · mesh sensitivity disclosed.	

Explicit limitations

Only one body-cell refinement was run; this is not a grid-convergence study.

The exact winner repeats above the drag cap on the search mesh, while a nearby point remains feasible.

S1223 has the better L/D (93 versus 82), and pitching stability, 3D tips, free-surface effects, and waves remain unresolved.

Recorded Archimedes run: 3.0 h autonomous swarm search (938 CFD solves). Compute record: 32 cloud workspaces · $174 total compute + tokens.